GPR Investigation for Marble Ornamental Exploration in Campos do Jordão Region: Preliminary Results

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Abstract

In this research, the GPR (Ground Penetrating Radar) method was applied for the characterization of a marble ornamental stone in Campos do Jordão region, São Paulo State. The geological setting is part of the Serra da Mantiqueira and is mostly formed by metamorphic rocks. The marble unit is at surface level in which fractures zones and folding zones are visible. GPR 2D and 3D for 270 MHz results presented fractures zones and unfractured marble blocks. The results serve as guidance to extraction of marble.

Introduction

According to Hilson (2003), Small-Scale Mining (SSM) is responsible for most of non-metallic substances production worldwide. In Brazil, SSM represents about 70% of the mining industry. SSM is characterized by limited use of machinery, precarious condition of labor, low level of professionalization, low efficiency and low productivity, and high environmental impact (Hentschel et al., 2004; United Nations Environment Programme, 2020).

The lack of geological knowledge can make the mine planning and stone exploration sub-optimal. Once there is an initial characterization of the rock deposit it is possible to optimize the mineral extraction, reduce expenses with probes and, with that, minimize waste and environmental impact.

In this study GPR profiles were performed directly at the rock unit, targeting fracture zones through 2D and 3D acquisition. The imaging produced this way can guide and help future mining planning as it highlights fracture zones and shows the marble massif to be exploited.

More and more has the GPR been employed in the mining industry, especially in the last 20 years. In Brazil, Porsani et al. (2004) identified greisen bodies zones, typically rich in tin ore in the Tin Province of Rondônia. This region is minerally desirable for its tin lodes. In 2005, Porsani et al. conducted a study integrating GPR, electrical resistivity, and nuclear techniques investigating fractures in a granite body that could be filled with water. This study made possible to evaluate the most favorable points for the municipality of Itu to drill wells for water supplying. Porsani et al. (2006) employed the GPR method to characterize granite rocks for block extraction in Capão Bonito, SP. The results showed fracture zones and granite massifs that were used for guiding the exploration.

More recently, Rey et al. (2015) used GPR as a non-destructive technique for evaluation and characterization of marble rock in both outcrops and individual block in Macael, Spain. In this study, a method known as probabilistic latent component analysis (PLCA) image enhancement was applied to the data for “denoising and separating target from non-target sources”. The authors were able to differentiate the marble unit from the mica schist as well as identify anisotropies and structures in the marble prior to cutting. Martinez et al. (2017) returned to Macael for further GPR investigations, this time with the additional method of electrical resistivity imaging (ERI). In this study, the authors evaluated the marble quality through the mapping of fracture zones and imperfections on the block.

In an analogous way to the aforementioned studies, the 2D and 3D GPR data obtained in this research will be integrated with available probing data to identify fracture zones and massif marble blocks which can be used for guiding future extraction while optimizing investments and making the SSM more profitable and sustainable.

Geological Setting

The region in which the study was performed is known as Campos do Jordão Plateau, characterized by banded biotite gneisses and mylonitic gneiss. This formation is part of the Serra da Mantiqueira Province and formed by multiple geological structures of folding and metamorphism that happened through the Brazilian Cycle by tectonic activity in the geosystem (Hiruma et al., 1999). Shaped by five different tectonic stress regimes that happened from the Paleogene to the Holocene periods, it is now composed of fracture and fold complexes (Hiruma et al., 2022).

This study’s geological setting is a marble mine located 15 km northeast of Campos do Jordão, SP, a famously known touristic city 140 km away from the state capital (Figure 1). The formation of marble bodies is uncommon in the Plateau and the proximity to grand urbanized centers is one of the reasons the mine was established. The responsible company is Mineração Corrêa LTDA, this being it’s second mining site at the region. The ornamental rocks extracted at the local are fully utilized and generates no waste.

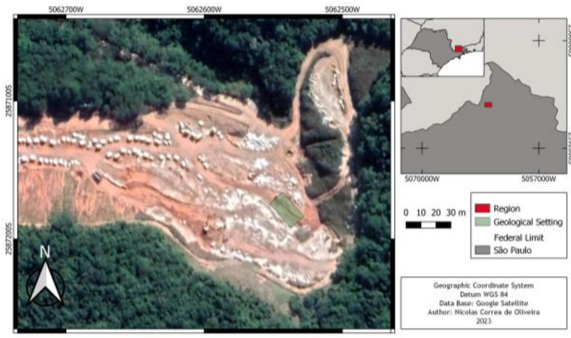

Figure 1 – Study area location map.

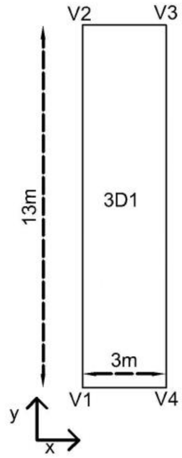

Figure 2 – Acquisition grid limits sketch.

Method

The Ground Penetrating Radar is a non-destructive electromagnetic prospection method that consists of the emission, propagation, reflection, and reception of high-frequency electromagnetic waves. It operates in the range of 10 MHz to 2,6 GHz and is capable to locate structures and geological features through the dielectric contrast between them (Daniels, 1996; Davis & Annan, 1989; Porsani, 1999).

The method generates a high-resolution image of the subsurface contents by the transmission of high frequency waves which are repeatedly radiated into the medium by a transmitter antenna and later captured by a receiver antenna. Waves are registered in travel time, which is double the distance, amplified, digitalized, and recorded on computer for processing (Daniels, 1996; Davis & Annan, 1989; Porsani, 1999; Poluha, 2017).

The propagation through the medium rapidly decays and the maximum range reached is calculated by a relation known as Skin Depth, ruled by the inverse of the dielectric constant. The higher dielectric permittivity the faster is the attenuation of the electromagnetic waves.

Data Acquisition and Processing

66 GPR profiles of 270 MHz antenna were acquired in a 3D grid (Figure 2), 53 in the X-direction (3 meters long) and 13 in the Y-direction (13 meters long). In both directions there was 0.25 m spacing between lines and point intervals of 0.02 m. The equipment used in the study were the GSSI SIR-4000 model.

The collected data was processed through Radan 7.0 software from GGSI. The processing stages were time zero correction, frequency and stacking filters, gain varying in time, background removal, migration, and time to depth conversion. Dielectric permittivity was corrected by adjusting a horizontal reflector at 3 meters deep, the result was equal to 8. Further information on data processing can be found in Yilmaz (1987).

Figure 3 – GPR data acquisition.

Preliminary Results

Figure 4 shows one of the multiple processed profiles at 0 m X along Y-direction. This radargram is directly related to the picture showed in Figure 3. It is possible to identify the inclined fracture that runs along the profile, with its shallowest point at 13 m position and 0.75 m depth and deepest at 0 m position and 4.5 m depth (Arrow 1 at Figs. 4 and 5). It is also possible to observe another inclined fracture that too runs along the profile, with its shallowest point at 4 m and deepest at 6.5 m (Arrow 2 at Figs. 4 and 5). The last target to be described is a horizontal fracture at 3 m deep as a strong reflector at the origin of the profile that fades around the center of the radargram (Arrow 3 at

Figs. 4 and 5). Both the first inclined fracture and the horizontal one can be seen in the Fig 3. Lastly, there is a noise zone at the radargram bottom that is related to the outcrop wall that was closer to the equipment as the electromagnetic waves reflected on it (Arrow 4 at Figs. 4 and 5).

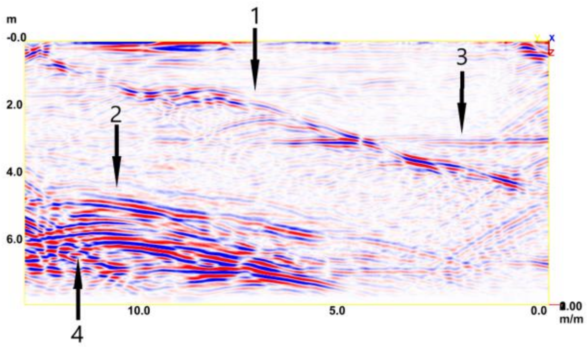

Figure 4 – 270MHz GPR profile-1 processed before migration.

Figure 5 is the result of migration (k = 8) process on Figure 4. As the radargram above, the migrated profile highlights the first inclined fracture, the horizontal fracture but it blends the second inclined fracture signal with the noise at the lowest part of the profile. This image provides a much better visualization of the reflectors and, with that, better defined borders of the massif marble as a result of the reflectionless areas.

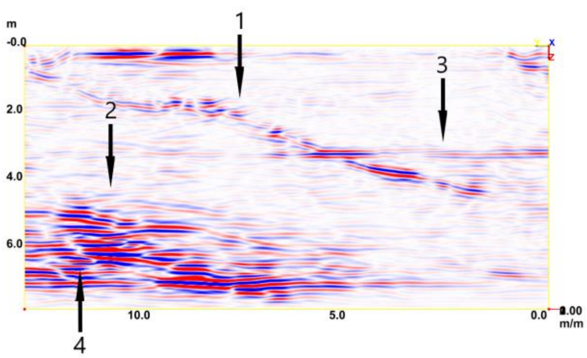

Figure 5 – 270MHz GPR profile-1 processed after migration.

Figure 6 shows one section of the 3D block with Z-slice at 2.1 meters depth and fence diagram in X and Y position. For this setting, the depth slice shows the way part of the inclined fracture extends through the marble both in X and Y directions. The bright red signal shows a strong reflection about 3 meters wide at 2.1 meters depth that crosses the whole section of the 3D block. This strong reflector can be seen along both profiles in the figure.

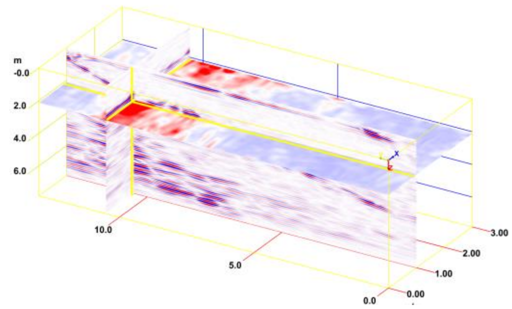

Figure 6 – 3D block with Z-slice at 2.1 meters depth and fence diagram in X and Y position.

The results presented in this article show that the application of GPR investigations on mining industry prove to be beneficial for the employers as was shown in past studies conducted by Porsani et al. (2004), Rey et al. (2015), and Martínez et al. (2017), among other.

Conclusions

The GPR profiles could locate and precisely define inclined and horizontal fractures. Better than that, the 3D grid was able to map the extension of fracture zones and discontinuities in a whole block while highlighting low energy regions.

Both the profiles and 3D array were able to reveal zones that show little to no reflections. The lack of reflections in a GPR profile means that there is no dielectric contrast in the interval, i.e., it is a homogeneous, non-fractured rock block. Those massif marble blocks are the mine main target and represent the most valuable resource to the company.

The results of this study are essential for the mine engineering as it is precise and highly productive data for mine planning.

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